



Universidade de Aveiro Departamento de Biologia
Ano 2009

**Fabiana Marisa
Vieira das Neves**

**Dinâmica de Cianobacterias na lagoa da Vela em
2008**



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Cyanobacteria dynamics at Vela Lake during 2008

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Microbiologia, realizada sob a orientação científica do Doutor Mário Jorge Verde Pereira, Professor Auxiliar do Departamento de Biologia da Universidade de Aveiro

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palavras-chave

Cianobacterias, Eutrofização, Dinâmica do fitoplancton, Lagoas pouco profundas, Parâmetros ambientais.

resumo

A lagoa da Vela, localizada no litoral Centro Português (Figueira da Foz), é uma lagoa superficial com características típicas de estado trófico avançado, utilizada para actividades recreativas e como fonte de água para a agricultura e pecuária. No presente estudo foi efectuada uma recolha anual (bimensal) de forma a compreender a variação sazonal dos parâmetros ambientais e fitoplâncton, e a influência dos primeiros na variação do fitoplâncton. Os parâmetros ambientais, como temperatura, pH, condutividade, oxigénio (% e dissolvido), nutrientes (nitratos, amónia, fósforo, sílica), clorofila *a* e sólidos totais, foram determinados também para, comparando com trabalhos anteriores sobre esta lagoa, compreender a evolução do estado trófico desta massa de água. O fitoplâncton foi dominado por Cianobactérias durante todo o período do estudo, com densidades entre $1,0 \times 10^5$ (Fevereiro) e $1,0 \times 10^6$ células/mL (Setembro). Este domínio foi acompanhado por valores baixos de oxigénio e nutrientes, e por valores elevados de pH, condutividade, clorofila *a* e sólidos totais. As espécies *Aphanizomenon flos-aquae* e *Cylindrospermopsis raciborskii* foram registadas em Abril e, desde Junho até Dezembro. Este trabalho também demonstra, por comparação com outros trabalhos, que o fitoplâncton e as variações de nutrientes observadas são muito diferentes daqueles descritos anteriormente na lagoa da Vela. No período em estudo identificaram-se as classes de fitoplâncton Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae and Cryptophyceae sendo que a classe dominante durante todo o ano foi a Cyanophyceae. Relativamente aos nutrientes, estes apresentavam valores muito baixos, especialmente fósforo, nitratos e amónia.

keywords

Cyanobacteria, Eutrophication, Phytoplankton dynamics, Shallow lake, Environmental parameters.

abstract

Vela Lake located in Portuguese littoral-centre (Figueira da Foz), is a shallow lake with typical characteristics of advanced trophic state used for recreational purposes and as a water source for agriculture and livestock. An annual sampling (bi-monthly) was carried out in the present study in order to understand the seasonal variation of environmental parameters and phytoplankton, and the influence of the first one on the phytoplankton variation. Environmental parameters such as temperature, pH, conductivity, oxygen (% and dissolved), nutrients (nitrate, ammonium, soluble reactive phosphorus, silica), chlorophyll *a* and Total suspended solids, were determined also to, by comparing with previous works on this lake, comprehend the evolution of the trophic status of this water body. The phytoplankton composition was dominated by Cyanobacteria during all study period, with densities between 1.0×10^5 (February) and 1.0×10^6 cells/mL (September). This dominance was accompanied by lowest values of oxygen and nutrients, and by highest values of pH, conductivity, chlorophyll *a*, and Total suspended solids. The taxa *Aphanizomenon flos-aquae* and *Cylindrospermopsis raciborskii* were recorded in April and since June to December. This work also demonstrates, by comparing with further works, that the phytoplankton and nutrients variations observed are very different than those described in Vela Lake. In the present study period were identified phytoplankton classes Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae and Cryptophyceae and the ruling class throughout the year was the Cyanophyceae. For nutrients, these had very low levels, especially phosphorus, nitrates and ammonium.

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1. Introduction

1.1. Cyanobacterial blooms (enhancement factors, cyanotoxins, toxic species)

Cyanobacteria or blue-green algae are prokaryotes and photosynthetic microorganisms (with chlorophyll *a* as their primary photosynthetic pigment) that can be found in freshwater, marine and terrestrial habitats with the ability to support extreme environments (Carneiro and Leite 2008). Usually cyanobacteria have microscopic dimensions but, depending on the environment conditions, can form massive blooms by dominating the phytoplankton with negative consequences in the water quality, the aquatic flora and fauna and public health, becoming a worldwide problem (Palus *et al.*, 2007).

Eutrophication is commonly recognized as a consequence of human activities and depends on the organic matter availability hence being indirectly linked to the chlorophyll concentration, and on others factors such as nutrients availability, light intensity and temperature (Anderson *et al.*, 2002; Gonçalves *et al.*, 2005; Sigee 2005). The eutrophication of surface freshwater is increasing worldwide mainly due to the pressure of anthropogenic activities on aquatic systems which are related to nutrient inputs from agriculture, livestock production, urbanization, industry and effluents discharge that lead to community changes and a deterioration of water quality. The common symptoms of eutrophication include dense phytoplankton blooms (with cyanobacterial dominance), an increase of the turbidity and particulate matter of the water, and anoxia in the deeper parts of the lake. All this has had a considerable impact on drinking and recreation water quality (Codd 2000; Anderson *et al.*, 2002; Havens *et al.*, 2003; Sigee 2005; Schindler *et al.*, 2008). Cyanobacterial blooms have been associated with high water temperature and column stability, high pH levels and low O₂ and ratio Total Nitrogen (TN): Total Phosphorus (TP) (Scheffer *et al.*, 1997; Vasconcelos 1999; Vázquez *et al.*, 2005). Timing and duration of the cyanobacterial bloom season depend largely on the climatic conditions of the region. Normally, in temperate zones, blooms of cyanobacteria are most prominent during the late summer and early autumn and may last for 2–4 months (van Apeldoorn *et al.*, 2007). These blooms are responsible for a decrease in water transparency, preventing the light from reaching deeper water and, therefore, only species able to migrate in water

column like cyanobacteria can be successful in this environment (Vasconcelos 2006).

Over the last decades coastal regions throughout the world have experienced what appears to be an escalation in the incidence of blooms. This shows a common feature – cyanobacteria have the ability to cause harm either due to the production of toxins or due to accumulated biomass affecting co-occurring organism and altering food web dynamics (Anderson *et al.*, 2002). Some Cyanobacteria produce extremely potent toxins and, even at low densities, blooms can be very dangerous. These toxic secondary metabolites include potent hepatotoxins (microcystins, nodularin), neurotoxins (anatoxin-a, homoanatoxin), cytotoxins (cylindrospermopsins), dermatotoxins (lyngbyatoxin) and irritant toxins (lipopolysaccharides). These compounds can cause death not only in aquatic organisms that come in direct contact with them, but also in livestock, domestic animals and wildlife, waterfowl, and more rarely, in humans (Vasconcelos 2001b; Anderson *et al.*, 2002; Mankiewicz *et al.*, 2003; Dittmann and Wiegand 2006; Sotero-Santos *et al.*, 2006; Vasconcelos 2006; Erdner *et al.*, 2008).

Microcystis spp. have the ability to produce microcystin (MC) which is a hepatotoxin with at least 75 variants and, depending on the specific chemical structure, they can be highly toxic to animals and people (Mankiewicz *et al.*, 2003; Carmichael and Li 2006) through oral consumption (drinking contaminated water or unintentional drinking during recreational use of the water bodies suffering from cyanobacterial biomass), inhalation (also during recreational use), consumption (food and food supplements) or haemodialysis (water improperly purified) (Jochimsen *et al.*, 1998; Mankiewicz *et al.*, 2003; Dittmann and Wiegand 2006; Hu *et al.*, 2009). Once ingested, this toxin cannot be destroyed by digestion and is transported to the liver (Mankiewicz *et al.*, 2003), causing hepatic failure and potential for promotion of tumour growth (Codd *et al.*, 2005). MC production is influenced by environment factors such as nutrients, light, pH and temperature (van Apeldoorn *et al.*, 2007) and is produced by other freshwater genera such as *Anabaena*, *Oscillatoria*, *Planktothrix*, *Nostoc*, *Anabaenopsis* and terrestrial genus *Haplosiphon* (Carmichael and Li 2006; van Apeldoorn *et al.*, 2007; Kurmayer and Christiansen 2009). In last year's several Portuguese freshwater bodies used for recreational or drinking purposes have been found with hepatotoxic blooms of MC (Vasconcelos *et al.*, 1996; Vasconcelos 2001a; Vasconcelos 2001b; Vasconcelos

and Perreira 2001, de Figueiredo *et al.*, 2004c). At Vela Lake, toxic strains of *Microcystis aeruginosa* have been reported in 1993 (Vasconcelos 1993) and latter in June/July 2001 a bloom of the same species (de Figueiredo *et al.*, 2006) was documented although its toxicity was unknown. In the present work this species was present during all the study period. *Aphanizomenon flos-aquae* has differentiated specialized cells for nitrogen fixation (heterocysts) which allow it to survive during nitrogen limitation (Dittmann and Wiegand 2006). This species can produce Saxitoxin, also known as Paralytic Shellfish Poison - PSP's, which are alkaloid tricyclic compounds that could be either non-sulphated (saxitoxins and neosaxitoxins), single sulphated (gonyautoxins), or doubly sulphated (C-toxins). In Cyanobacteria, these toxins have been found in *Aphanizomenon flos-aquae*, *Aphanizomenon* sp., *Aphanizomenon issatschenkoi*, *Anabaena circinalis*, *Planktothrix* sp. and benthic *Lyngbya wollei* (van Apeldoorn *et al.*, 2007; Herrero and Flores 2008; Kurmayer and Christiansen 2009).

1.2. Blooms of cyanobacteria and phytoplankton seasonal succession at Vela Lake over the last decade

The shallow Vela Lake (Figueira da Foz, Portugal) has been considered eutrophic since 1960 (Nauwerck 1960). Since then many studies made on this lake achieved similar conclusions, describing high P and N levels and turbid water (Barros 1994; Gonçalves *et al.*, 1996; Antunes *et al.*, 2003; Abrantes *et al.*, 2006; Vasconcelos 2006; de Figueiredo *et al.*, 2007; Abrantes *et al.*, 2008; Lopes *et al.*, 2009).

In the last decade some studies have been made and published in order to observe this lake's status, concerning the seasonal variation of phytoplankton and physicochemical parameters (Antunes *et al.*, 2003; Abrantes *et al.*, 2006; de Figueiredo *et al.*, 2006; Lopes *et al.*, 2009). These works showed a considerable increase of the eutrophication level of Vela Lake.

Some authors such as Antunes *et al.* (2003), Abrantes *et al.* (2006) and de Figueiredo *et al.* (2006) have described that phytoplankton seasonal succession in Vela Lake was highly correlated with temperature and nutrients. During the autumn-winter period (low temperatures and high N, SiO₂ and P levels) the Bacillariophyceae group is dominant, whereas Chlorophyta dominate in the early

spring (decrease in nutrients as P) and Cyanobacteria in the late spring and summer period (increase of light and temperature, and decrease of N and P concentrations). This dynamics has been documented by other authors in temperate lakes (Sigee 2005). During cyanobacterial dominance there are often observed blooms of potentially toxic cyanobacteria such as *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* (Abrantes *et al.*, 2006; de Figueiredo *et al.*, 2006). *Microcystis aeruginosa* is able to produce hepatotoxins such as microcystins (MC) (de Figueiredo *et al.*, 2004c). Vasconcelos and collaborators (1993) have reported toxic strains of *Microcystis aeruginosa* at Vela Lake. *Aphanizomenon flos-aquae* can produce neurotoxins such as saxitoxins, also known as paralytic shellfish poison - PSP's (van Apeldoorn *et al.*, 2007; Herrero and Flores 2008; Kurmayer and Christiansen 2009). This species was recorded in Vela Lake in May 2001 during a work of de Figueiredo and collaborators (2006) and Abrantes and collaborators (2006) and related with low nitrogen levels which made this species an advantageous competitor (due to nitrogen fixation ability) towards the other phytoplankton organisms.

1.3. Objectives and structure of thesis

This work intends to study the seasonal variation (from December 2007 to December 2008) of environmental parameters and phytoplankton assemblage at the shallow eutrophic Vela Lake (Figueira da Foz, Portugal). It also aims to explore the influence of environmental conditions on the seasonal variation of the phytoplankton, particularly on the development of cyanobacterial blooms. Additionally, it is made a comparison of the present data with a previous work (from 2001) (de Figueiredo *et al.*, 2006), in order to comprehend the evolution of the lake trophic status, and investigate if conditions compatible with global warming may have had any effect on the differences found.

This dissertation works is composed by 6 sections. The first one is the introduction in which the importance of cyanobacterial blooms' study is highlighted. The second section includes the description of material and methods where the study area, the sampling strategy, environmental parameters analysis, phytoplankton enumeration and statistical analysis are explained. The results obtained are presented in the third section and discussed in the fourth one. On the

fifth section there are made the general conclusions from this work. The sixth section shows all the references used to fundament this dissertation.

2. Material and Methods

2.1. Study area

Vela lake is a shallow eutrophied freshwater (mean depth = 0.9m; maximum depth = 2.4m) located in the littoral-centre of Portugal, Quiaios – Figueira da Foz (40°5'N 8°8'W, 45m elevation) 6 Km away from the Atlantic Ocean (Figure 1). It has an area of approximately 70 ha and a total volume of $70 \times 10^4 \text{ m}^3$. The lake is surrounded by some agricultural fields, settlements, sandy soil and forest (*Pinus* spp. and *Acacia* spp.) This lake is used for recreational and agricultural purposes and characterized by highly eutrophication with permanent turbid water, and is also frequent to observe algal blooms mainly in warmer seasons (Abrantes *et al.*, 2006; de Figueiredo *et al.*, 2006). On the last decade it has been reported an increase of the nutrient levels that come from human activities like agriculture and land modification (Antunes *et al.*, 2003; Abrantes *et al.*, 2006; de Figueiredo *et al.*, 2006; Lopes *et al.*, 2009).

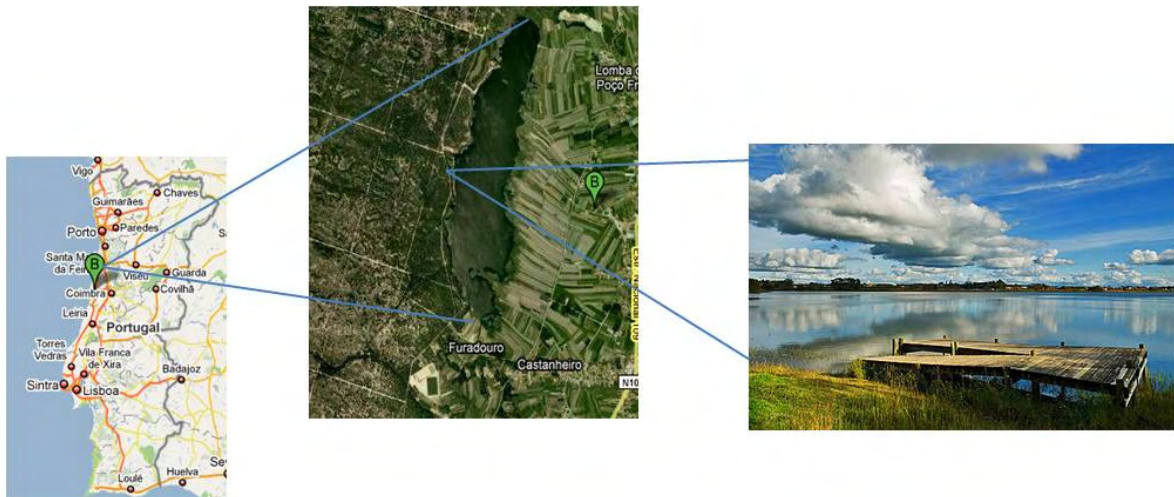


Figure 1. Location of Vela Lake and sampling site.

2.2. Sampling Strategy

Water samples were collected fortnightly just below the water surface, over a 1-year period (from December 2007 to December 2008), always in the same place (40°16'N 8°47'W – Figure 1) and by the same hour (around 12:00h). Samples were enumerated according to the sequential days of sampling. In each sampling day water samples were collected for determination of chemical parameters (phosphates, nitrates, ammonia, total suspend solids (TSS)) and Chlorophyll *a* – Chl *a* - (as an estimate of algal biomass) into a 1.5L plastic bottle

and transported in a refrigerated bag to the laboratory, in the dark at 4°C. Water was also collected for DNA extraction and investigation of prokaryote dynamics through molecular approaches (data not included in the present dissertation).

2.3. Environmental Parameters Analysis

The following parameters were measured in the field using portable water testing meter (WTW Multiline P4): pH, water and air temperature, electrical conductivity and dissolved oxygen. In the laboratory, ammonia ($\text{NH}_4^+\text{-N}$) was determined through indophenol blue method according Rodier (2005), and nitrates (molecular absorption spectrophotometry method; $\text{NO}_3^-\text{-N}$), soluble reactive phosphorus – SRP (acid ascorbic method; PO_4^{3-}), and silica (molybdosilicate method; SiO_2) were quantified according to methodologies described by APHA (2005). For the determination of TSS, samples were filtered through preweighted filters (Whatman GF/C) and the solids were calculated according to the APHA (2005). For Chl *a* the water was filtered on glass fibre filters (Whatman GF/C) and extracted in 90% acetone in the dark, following APHA (2005).

2.4. Phytoplankton Enumeration

For phytoplankton analyses a 1L sample was preserved into a glass bottle with Lugol solution (1% v/v) for subsequent identification and enumeration. The quantitative measurements of phytoplankton were made using the sedimentation technique according the APHA (2005), counting at least 400 species in an inversion optical microscope (Utermöhl method), following Lund *et al.* (1958). The identification was performed using different references for Cyanobacteria (Bourrelly 1970; Komárek and Anagnostidis 1989), Chlorophyta (Bourrelly 1972; Komárek and Fott 1983), Bacillariophyceae (Bourrelly 1968; Germain 1981), Cryptophyceae (Bourrelly 1970) and Euglenophyceae (Bourrelly 1970).

2.5. Statistical analysis

The distribution of samples according to environmental parameters was assessed through Principal Component Analysis (PCA) (Pearson 1901) after environmental parameters data standardization (subtracting the mean from each observation and dividing by the corresponding standard deviation) and the data of phytoplankton community was logarithmically transformed. Dendrograms were also created with the similarities calculated using the Pearson correlation coefficient (95% probability) and the PRIMER 6 software (Clarke and Gorley 2006). Pearson correlation coefficient was also used to assess significant correlations between environmental parameters and between phytoplankton considering their occurrence and relative densities. Canonical correspondence analysis (CCA) (ter Braak 1986) was performed to verify relationships between the distribution of the dominant genera/species and environmental variables.

3. Results

3.1. Environmental parameters and chlorophyll a

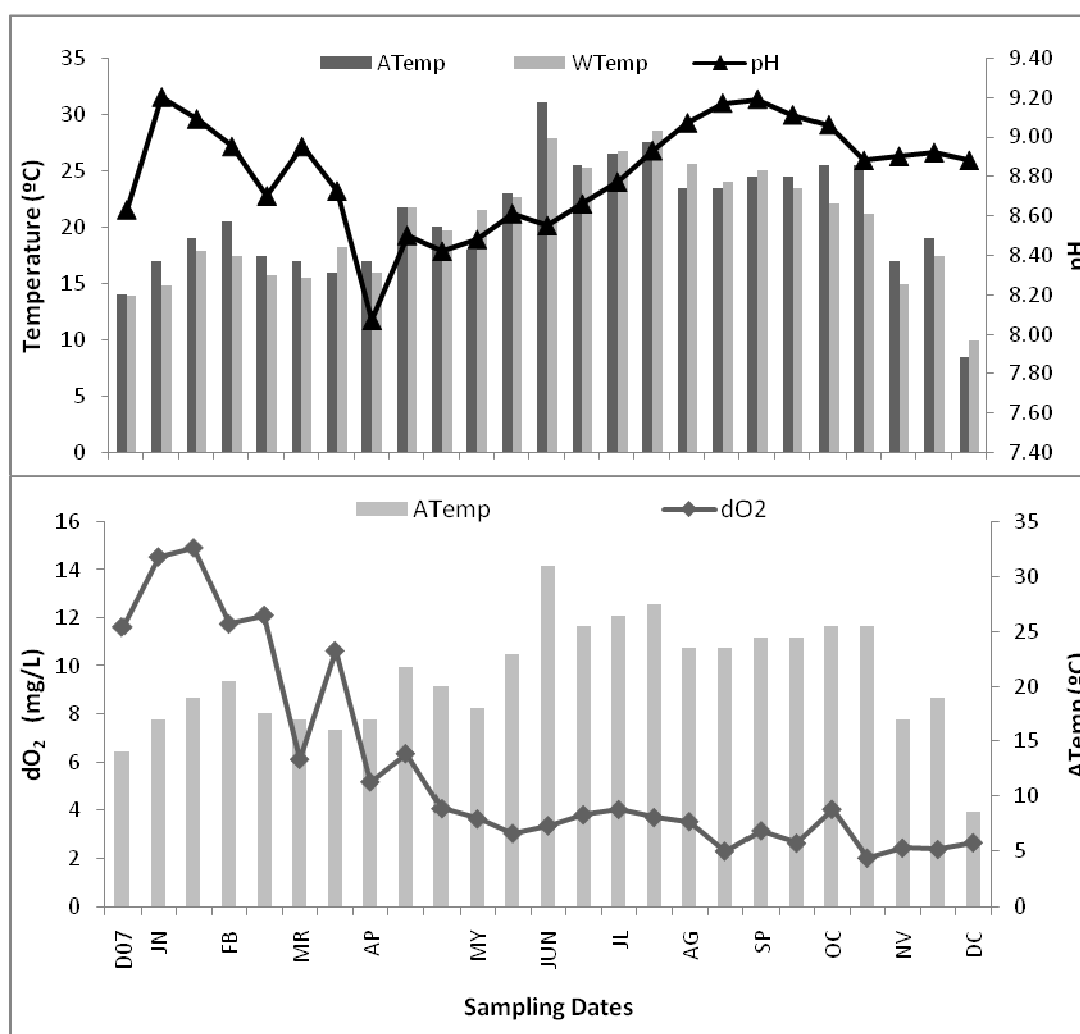
The environmental parameters were determined for each sample and are presented (with corresponding codes) in Table 1 and Figure 2. During the study period (December 2007 to December 2008) the water temperature (WTemp) ranged between 10°C and 28.5°C with lowest temperature registered in December 2008 and the highest in July (as observed for the air temperature (ATemp)). pH values were alkaline during all year, showing a minimum of 8.07 in April and a maximum of 9.20 in January. The conductivity levels (Cond) showed a minimum of 527 µS/cm (April) and had the highest levels between October and December 2008 (955 µS/cm – November). The levels for dissolved oxygen (dO₂) ranged from 1.98 (in October) to 14.90 mg/L (January), and the oxygen saturation (%O₂) followed the same trend with a minimum of 22.30 % and a maximum of 155.80 % in the same months.

Table 1. Environmental data recorded during the one-year study period (from December 2007 to December 2008) in Vela Lake (0.0 - undetectable).

		WTemp (°C)	ATemp (°C)	Cond (µS/cm)	pH	dissO ₂ (mg/L)	%O ₂	Chl a (µg/L)	TSS (mg/L)	SRP (mg/L)	NO ₃ ⁻ -N (mg/L)	NH ₄ ⁺ -N (mg/L)	SiO ₂ (mg/L)
2007	December (DC07)	13.9	14.0	639	8.63	11.60	123.30	114.98	53.4	0.0	0.2	0.0	6.8
	January (JA)	14.8	17.0	669	9.20	14.52	142.40	96.77	81.0	0.0	0.1	0.0	4.1
2008	February (FB)	17.9	19.0	618	9.09	14.90	155.80	155.38	50.1	0.0	0.0	0.0	2.1
	March MR)	17.4	20.5	606	8.95	11.73	131.40	151.75	120.1	0.0	0.1	0.0	1.5
		15.8	17.5	599	8.70	12.09	121.40	150.51	45.1	0.0	0.0	0.0	0.4
		15.5	17.0	622	8.95	6.09	60.00	117.26	115.0	0.0	0.1	0.0	0.1
		18.2	16.0	627	8.73	10.61	114.70	65.27	77.0	0.0	0.0	0.0	0.2
		16.0	17.0	639	8.07	5.15	55.20	86.25	59.6	0.0	0.0	0.0	0.0
	April (AP)	21.7	21.8	574	8.50	6.33	73.00	74.92	73.1	0.0	0.0	0.0	0.0
		19.7	20.0	527	8.42	4.04	45.00	128.94	62.5	0.0	0.1	0.0	0.2
		21.5	18.0	557	8.48	3.61	41.30	116.34	105.0	0.0	0.0	0.0	0.7
	May (MY)	22.6	23.0	550	8.61	3.01	35.40	85.55	83.2	0.0	0.0	0.0	0.5
		27.9	31.0	555	8.55	3.33	42.40	82.87	16.1	0.0	0.0	0.0	2.1
	June (JN)	25.3	25.5	580	8.66	3.78	46.20	85.59	43.2	0.0	0.0	0.0	0.7
		26.7	26.5	601	8.77	4.00	50.30	128.67	90.0	0.1	0.0	0.1	1.0
	July (JL)	28.5	27.5	643	8.93	3.67	47.10	184.65	145.0	0.0	0.0	0.0	1.1
		25.6	23.5	710	9.07	3.50	43.10	172.83	166.0	0.0	0.0	0.1	1.1
	August (AG)	24.0	23.5	738	9.17	2.27	27.60	237.52	135.0	0.0	0.0	0.0	0.9
		25.0	24.5	797	9.19	3.12	38.10	223.82	150.0	0.0	0.0	0.1	1.3
	September (SP)	23.4	24.5	815	9.11	2.60	30.50	235.98	160.0	0.0	0.0	0.1	1.2
		22.1	25.5	883	9.06	4.01	46.10	257.96	180.0	0.0	0.0	0.1	1.1
	October (OC)	21.2	25.5	916	8.88	1.98	22.30	294.89	160.0	0.0	0.0	0.0	1.4

November	14.9	17.0	955	8.90	2.40	24.00	221.24	135.0	0.0	0.0	0.1	1.6
(NV)	17.4	19.0	952	8.92	2.34	25.10	158.47	108.0	0.0	0.0	0.1	1.3
December	10.0	8.5	639	8.88	2.62	24.20	96.63	90.0	0.0	0.0	0.2	0.9
(DC)												

The nitrate (NO₃-N) concentration remained below 0.1 mg/L with the exception of December 2007 where 0.2 mg/L was detected, while ammonium (NH₄-N) levels ranged between 0 and 0.2 mg/L (December 2008). Soluble reactive phosphorus (SRP) concentration was undetectable (<0.1 mg/L) for most samples but showed a maximum of 0.1 mg/L in July. The silica (SiO₂) concentration showed a maximum in December 2007 (6.8 mg/L) and a minima between the end of February and April. Total suspended solids (TSS) showed a minimum value at June (16.1 mg/L) and maximum at October (180 mg/L) while chlorophyll a concentration ranged between 65.27 µg/L (in March) and 294.89 µg/L (in October).



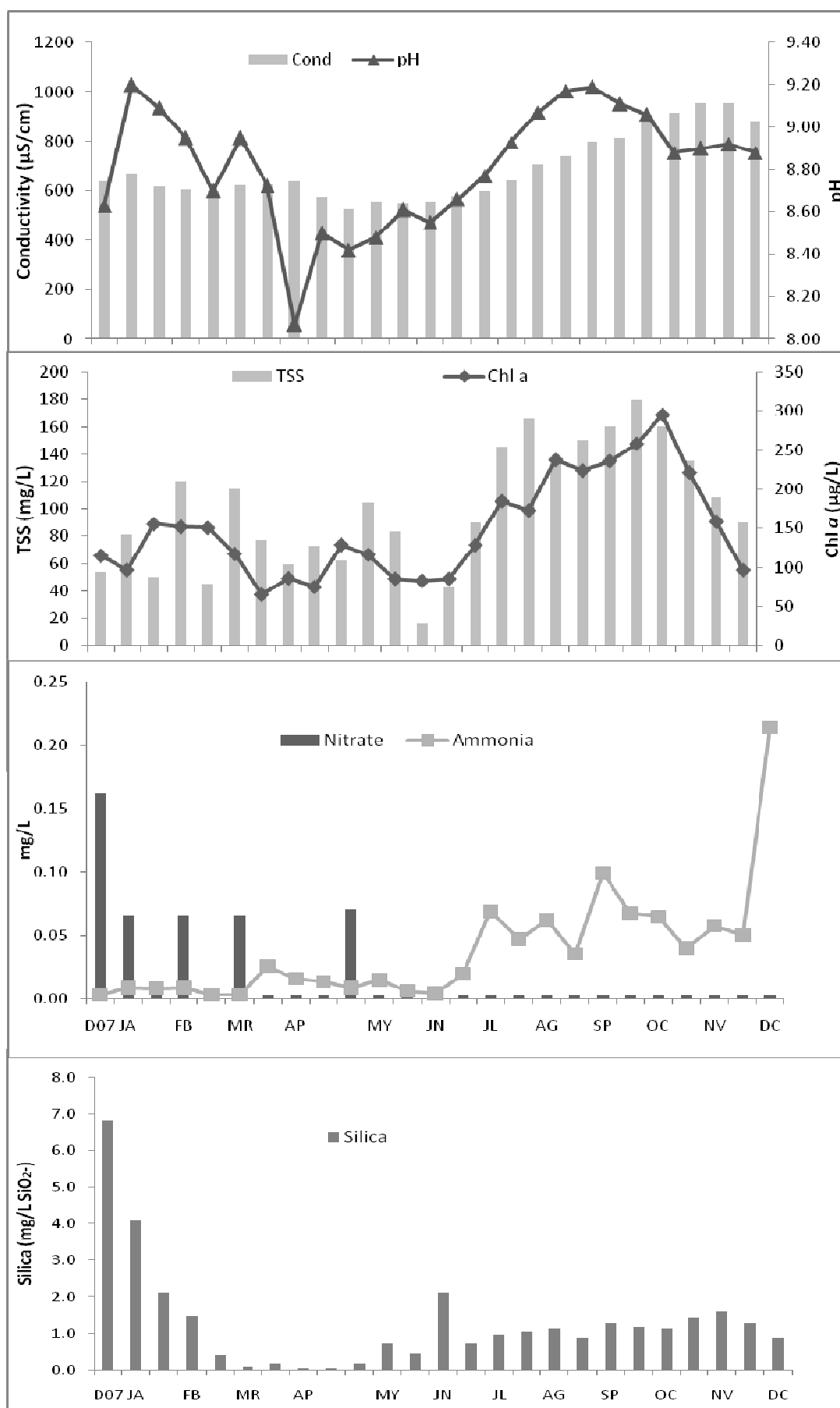


Figure 2. Variation of physical and chemical characteristics of Vela Lake water during study period (from December 2007 to December 2008).

3.2. Phytoplankton Composition

During the study period there were identified in Vela Lake the phytoplankton classes Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae and Cryptophyceae. The genera recorded are presented in Table 2 and their annual variation in Figures 3 - 6.

Table 2. Algal *taxa* recorded for Vela Lake during the study period (from December 2007 to December 2008).

Cyanophyceae (CYA)	<i>Aphanizomenon flos-aquae</i>	APH
	<i>Cylindrospermopsis raciborskii</i>	CYL
	Other_filamentous cyanobacteria	OFIL
	<i>Microcystis aeruginosa</i>	MIC
	Other_colonial cyanobacteria	OCOL
Chlorophyceae (CHL)	<i>Tetraedron minimum</i>	TET
	<i>Tetraedron caudatum.</i>	
	<i>Scenedesmus</i> spp.	SCE
	<i>Pediastrum</i> spp.	PED
	<i>Botryococcus braunii</i>	BOT
	Other_Chloroph	OCHL
Bacillariophyceae (BAC)	<i>Aulacoseira granulate</i>	AUL
	<i>Aulacoseira ambigua</i>	
	<i>Cyclotella</i> sp.	CYC
	Other_diatoms	ODIA
Cryptophyceae	<i>Cryptomonas</i> sp.	CRP
Euglenophyceae	<i>Trachelomonas</i> sp.	EUG

Cyanobacteria dominated the phytoplankton assemblage during all year with densities ranging from a minimum of 1.5×10^5 cells/mL in February and a maximum between 7.7×10^5 cells/mL in August and 7.3×10^5 cells/mL in November (highest value quantified was 1.0×10^6 cells/mL in September). This dominance period was accompanied by the lowest values for dO_2 (1.38 – 4.01 mg/L), % O_2 (22.3 – 41.1), nutrients (SRP and NO_3-N – 0 mg/L; $NH_4-N \approx 0$ mg/L; and SiO_2 - 0.9 – 1.6 mg/L). The highest values of pH (8.88 – 9.19), conductivity (738 – 955 $\mu S/cm$), Chl *a* (221.24 – 294.89 $\mu g/L$) and TSS (135 – 180 mg/L) were registered in this period while WTemp and ATemp ranges were 14.9 – 25.0°C and 17.0 – 25.5°C, respectively. In general, the filamentous forms of Cyanobacteria were the

most abundant, followed by the colonial form *Microcystis* spp. (Figure 4). In April and from June to December 2008 there were always present the taxa *Aphanizomenon flos-aquae* and *Cylindrospermopsis raciborskii*.

Relatively to the Chlorophytes and Diatoms their presence was stable and in low densities during all the study period (Figure 5 and 6) although there was verified a slight increase in their densities at the same time as the Cyanobacteria. The densities of Chlorophytes varied between 4.2×10^3 (January) – 2.8×10^4 cells/mL (November) with *Scenedesmus* spp. been the genera with highest densities. Diatoms varied between 36 (January) – 8.4×10^2 cells/mL (August). As said above, this increase was related to lower values of dO_2 , $\%O_2$ and nutrients, and by the highest values of pH, conductivity, Chl *a* and TSS.

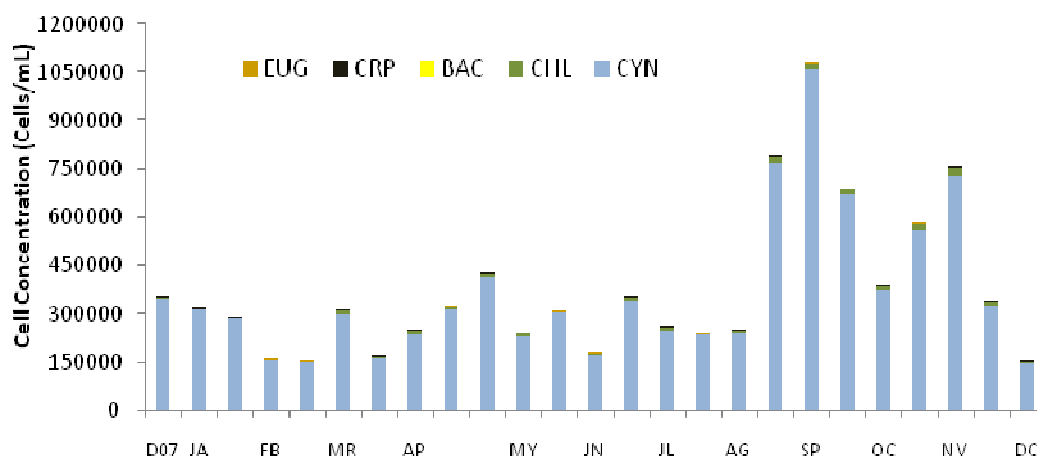


Figure 3. Variation of total phytoplankton abundance during the studied period.

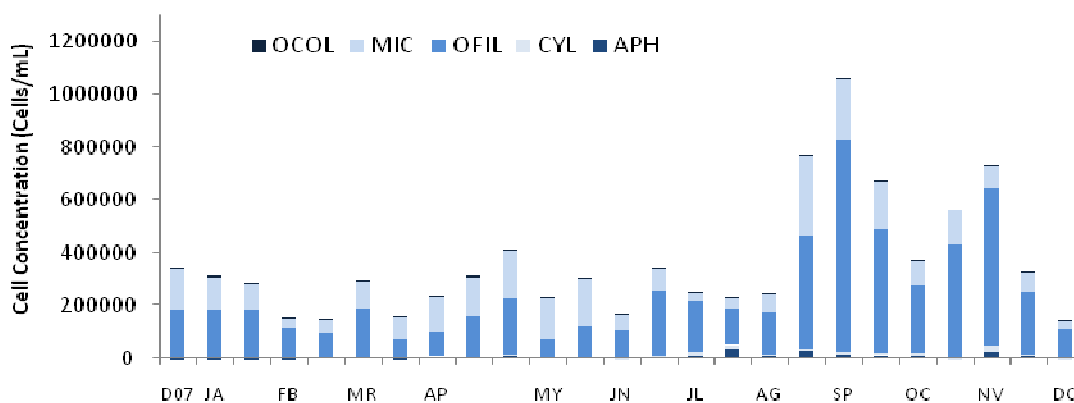


Figure 4. Variation of the Cyanobacteria diversity and abundance during the study period.

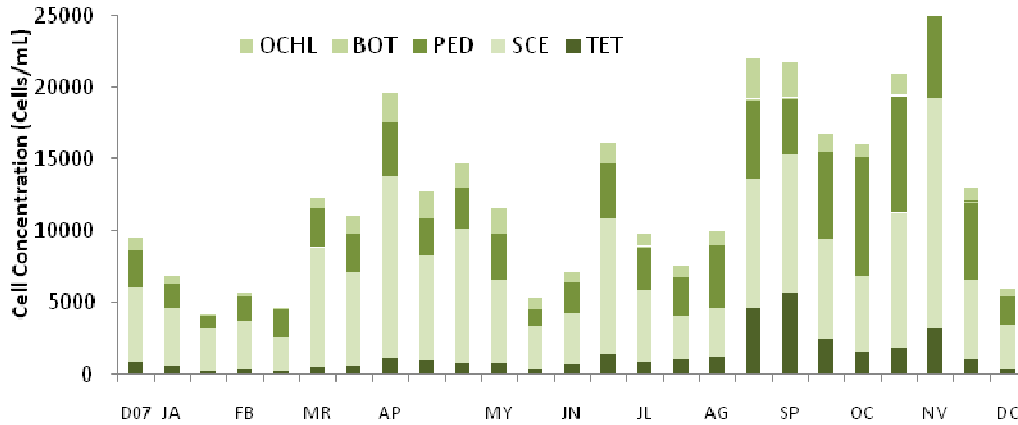


Figure 5. Variation of the Chlorophyta diversity and abundance during the study period.

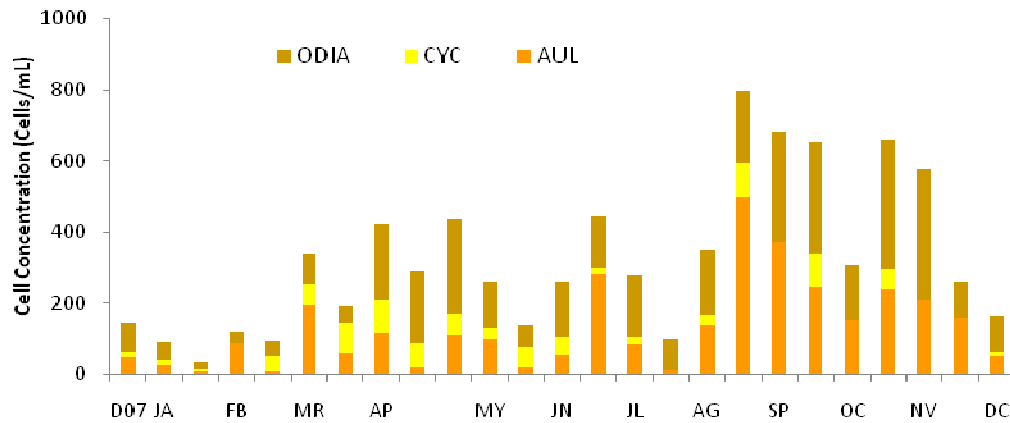


Figure 6. Variation of diatoms diversity and abundance during the study period.

3.3. The Pearson Relationship and Canonical Correspondence Analysis

The Pearson correlation coefficient values (Table 3) revealed relationships between the recorded environmental parameters and phytoplankton abundance ($n = 25$). Water temperature was highly significantly positively correlated with air temperature ($r = 0.93$, $P < 0.001$), but showed significant negative correlations with dissolved oxygen ($r = -0.45$, $P < 0.05$) and nitrate ($r = -0.42$, $P < 0.05$) concentrations. The dissolved oxygen and oxygen saturation levels were also highly correlated ($r = 1.0$, $P < 0.001$) and both these parameters showed also positive correlations ($P < 0.05$) with nitrate ($r = 0.47$ and 0.46 , respectively) and

silica ($r = 0.43$ for both) concentrations. In fact, silica and nitrate concentrations showed to be highly correlated as well ($r = 0.70$, $P < 0.001$). However, negative significant correlations ($P < 0.05$) were observed between dissolved oxygen / oxygen saturation levels and ammonium ($r = -0.44$ and -0.46 , respectively) but also TSS ($r = -0.44$ for both). On the other hand, TSS had highly significant relationships with Chl *a* ($r = 0.79$, $P < 0.001$), conductivity ($r = 0.64$, $P < 0.001$) and pH ($r = 0.61$, $P < 0.01$). The pH also showed a significant correlation with Chl *a* ($r = 0.59$, $P < 0.01$) while conductivity had also positive correlations with Chl *a* ($r = 0.68$, $P < 0.001$), ammonium ($r = 0.61$, $P < 0.01$) and pH levels ($r = 0.51$, $P < 0.05$) but a negative correlation with oxygen saturation levels ($r = -0.43$, $P < 0.05$).

The Pearson correlation coefficient was also used to reveal relationships between the environmental parameters and the phytoplankton abundances (Table 3). Water temperature showed to be correlated with APH ($r = 0.41$, $P < 0.05$) and BOT ($r = 0.58$, $P < 0.01$). TSS have had a positive correlation with all filamentous forms of Cyanobacteria (APH ($r = 0.51$, $P < 0.01$), CYL ($r = 0.4$, $P < 0.05$) and OFIL ($r = 0.53$, $P < 0.01$)), the chlorophytes TET ($r = 0.52$, $P < 0.01$) and PED ($r = 0.68$, $P < 0.001$), and diatoms such as AUL ($r = 0.48$, $P < 0.05$). Chl *a* was also positively correlated with the development of filamentous cyanobacteria (APH ($r = 0.5$, $P < 0.01$); CYL ($r = 0.46$, $P < 0.001$); OFIL ($r = 0.70$, $P < 0.05$), as well as the same chlorophytes (TET ($r = 0.63$, $P < 0.001$) and PED ($r = 0.77$, $P < 0.001$)) and diatoms (AUL ($r = 0.58$, $P < 0.01$)) referred above. Conductivity showed positive correlations with the growth of CYL ($r = 0.40$, $P < 0.05$) and OFIL ($r = 0.59$, $P < 0.01$), TET ($r = 0.46$, $P < 0.05$), PED ($r = 0.74$, $P < 0.001$) and AUL ($r = 0.43$, $P < 0.05$). TET ($r = 0.42$, $P < 0.05$) and filamentous cyanobacteria (including *Leptolyngbya* sp. – data not shown) (OFIL ($r = 0.50$, $P < 0.05$)) showed to be correlated with pH. In general, Chlorophytes had negative correlations with %O₂ (TET ($r = -0.44$, $P < 0.05$); SCE ($r = -0.40$, $P < 0.05$); PED ($r = -0.59$, $P < 0.01$) and OCHL ($r = -0.53$, $P < 0.01$)) and with dO₂ (TET ($r = -0.44$, $P < 0.05$), PED ($r = -0.58$, $P < 0.01$) and OCHL ($r = -0.53$, $P < 0.01$)).

Table 3. Pearson relationship between environmental parameters and phytoplankton abundances (*P<0.05; **P<0.01; ***P<0.001).

	ATemp	WTemp	Cond	pH	dO ₂	% O ₂	TSS	Chl <i>a</i>	NO ₃ -N	SRP	NH ₄ -N	SiO ₂
ATemp		0,928***			-0,452*							
WTemp									-0,421*			
Cond				0,505*		-0,432*	0,635***	0,677***			0,614**	
pH							0,608**	0,591**				
dO₂						0,995***	-0,436*		0,469*			0,433*
% O₂							-0,435*		0,462*		-0,458*	0,426*
TSS								0,790***				
Chl <i>a</i>												
NO₃-N												0,697***
SRP												
NH₄-N												
SiO₂												
APH		0,409*			-0,429*	-0,410*	0,507**	0,510**				
CYL			0,402*				0,446*	0,456*				
OFIL			0,586**	0,495*			0,525**	0,696***				
MIC												
OCOL												
TET			0,463*	0,416*	-0,437*	-0,434*	0,517**	0,627***				
SCE						-0,403*						
PED			0,744***		-0,575**	-0,586**	0,682***	0,773***				
OCHL					-0,532**	-0,533**						
AUL			0,425*		-0,508**	-0,512**	0,480*	0,578**				
CYC												
BOT	0,475*	0,576**										
ODIA			0,468*		-0,640***	-0,645***	0,441*	0,570**				
CRP										0,447*		
EUG												

Cluster analysis according to environmental parameters (Figure 7) shows a clear seasonal separation of samples. Principal Component Analysis (Figure 8) also evidences the seasonal gradient from the dendrogram with the first axis generally defined by late summer and early autumn samples on the negative side and winter sample 15DC07 followed by the other winter samples on the positive side. This axis showed to be mainly defined by oxygen and nitrate levels but also water and air temperatures, and TSS and Chl *a* levels. The second axis was defined by samples 1AP08 and 11JN08 and the other spring and early summer samples on the negative side and the winter samples 15DC07 and 9JA08 on the positive side and was mostly related to pH. The first two axes of the PCA accounted for 53 % of the total variance of samples distribution (Table 4).

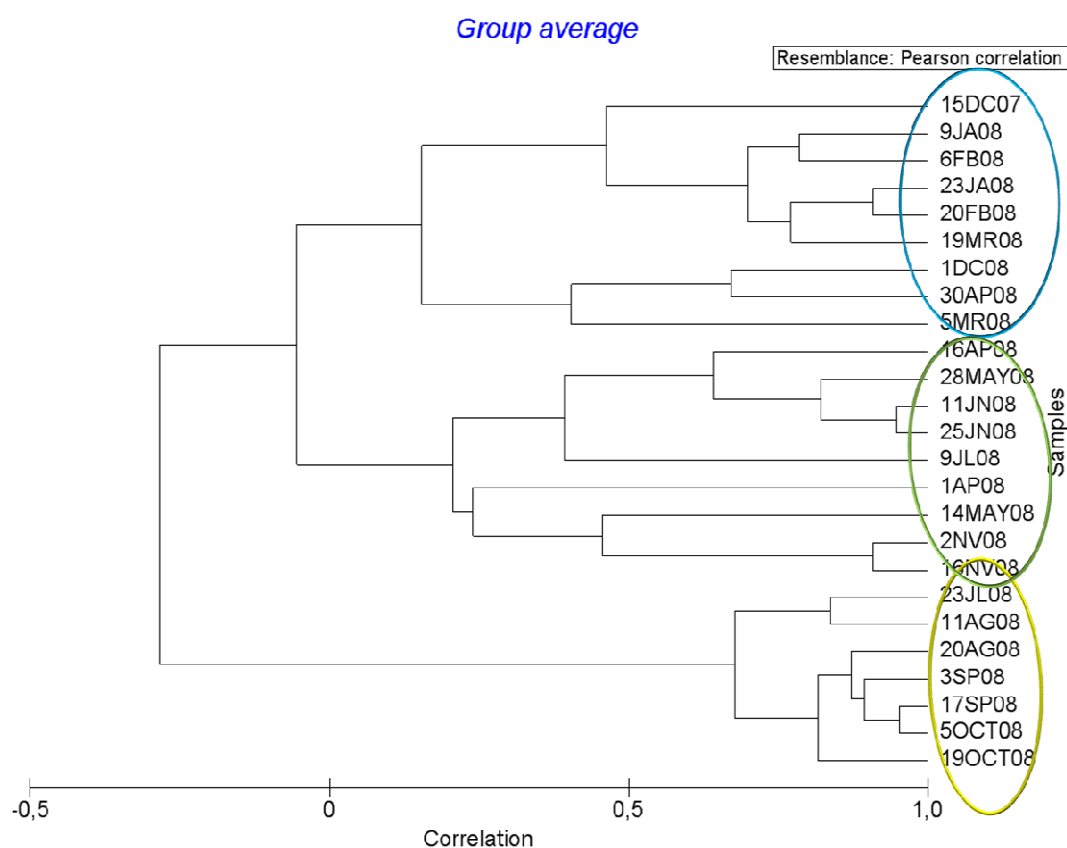


Figure 7. Cluster analysis of 2008 samples according to the environmental parameters.

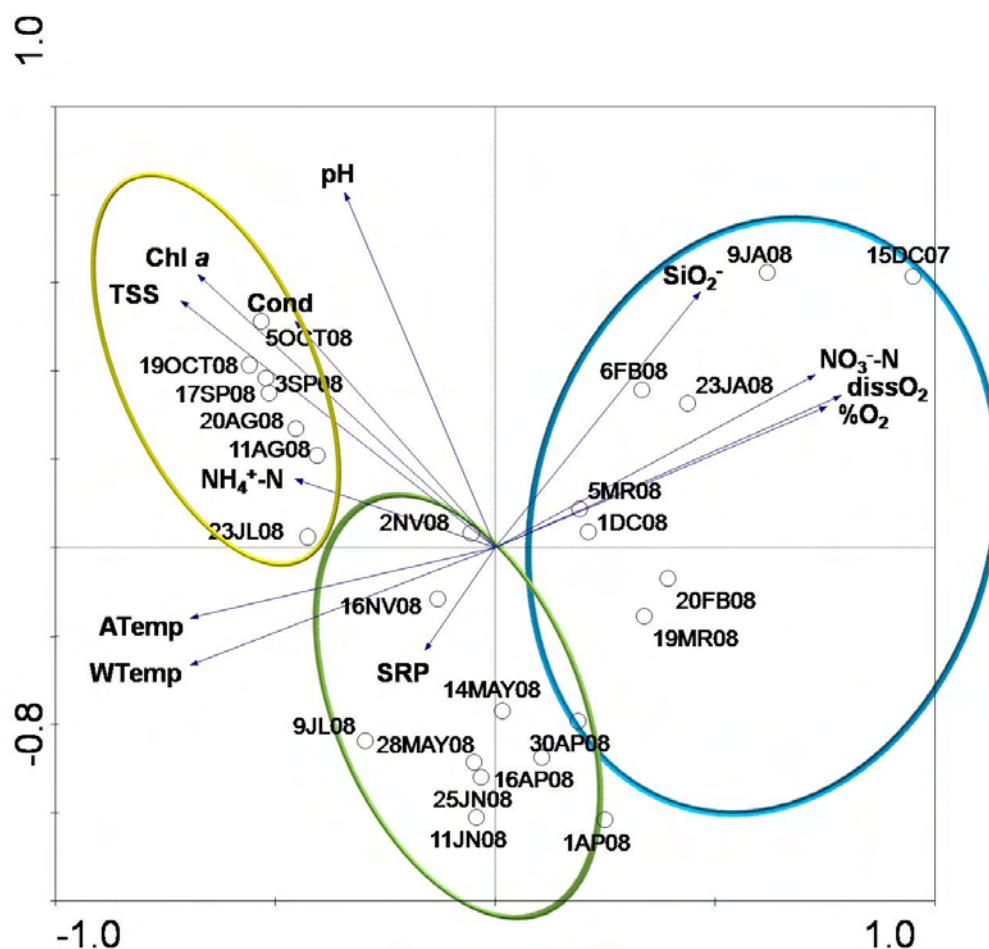


Figure 8. Principal Component Analysis ordination biplot of samples according to environmental parameters during the study period.

The results of CCA (Figure 9) adjustment of the phytoplankton genera and some species registered and the environmental parameters allows to conclude that the first axis is mainly defined by pH, $\text{NH}_4^+\text{-N}$, Chl *a*, conductivity and WTemp levels; the positive side is defined by diatoms (CYC), Euglenophytes (EUG) and the spring samples whereas the negative side was defined by BOT and sample 3SP08. The second axis was related with water temperature, dissolved oxygen, SiO_2 , $\text{NO}_3^-\text{-N}$ and SRP. Cyanobacteria (CYL, APH) and summer samples define the positive side and the negative side is defined by winter samples and, in spite of not having a clear segregation, diatoms CYC and AUL, and Cyanobacteria MIC and OFIL. The first two axes of the CCA accounted for 76 % of the total variance of samples and species distribution (Table 4).

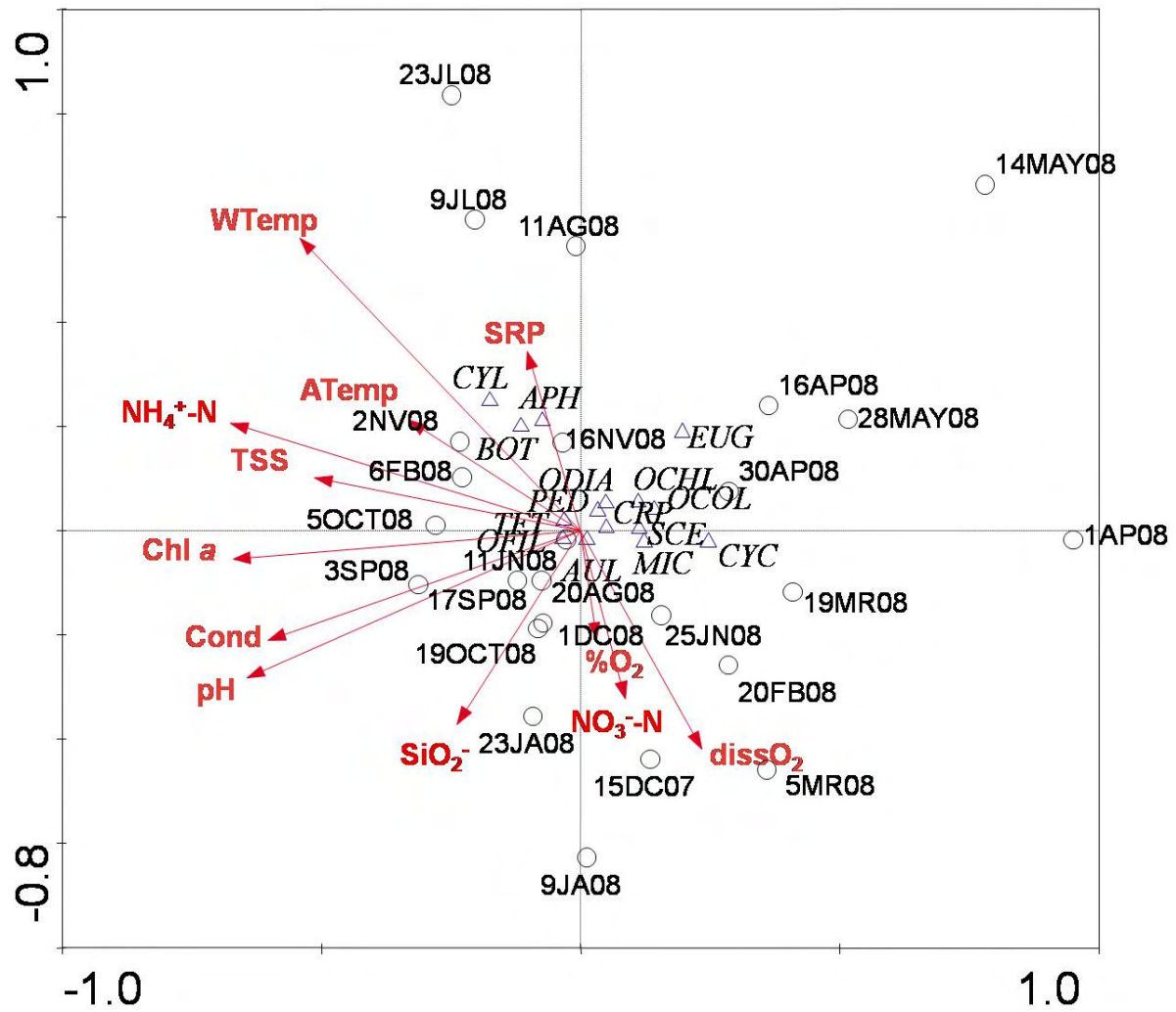


Figure 9. Canonical Correspondence Analysis triplot of the phytoplankton genera/species and samples according to the environmental parameters determined during the study period.

Table 4. Summary of canonical correspondence analysis

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.049	0.019	0.011	0.005
Species-environment correlations	0.946	0.785	0.882	0.712
Cumulative percentage variance:				
of species data	38.1	53.3	61.7	65.3
of species-environment relation	54.2	75.8	87.7	92.8

Sum of all eigenvalues	0.128
Sum of all canonical eigenvalues	0.090
Variance explained by the CCA	70.3 %

3.4. Historical environmental contextualization and 2008 atypical conditions

In order to assess potential environmental changes in 2008 which may have enhanced the development of *C. raciborskii* blooms, a comparison with environmental data having the same sampling periodicity was performed. These data are from 2000/2001 and have been published elsewhere (de Figueiredo *et al.*, 2006).

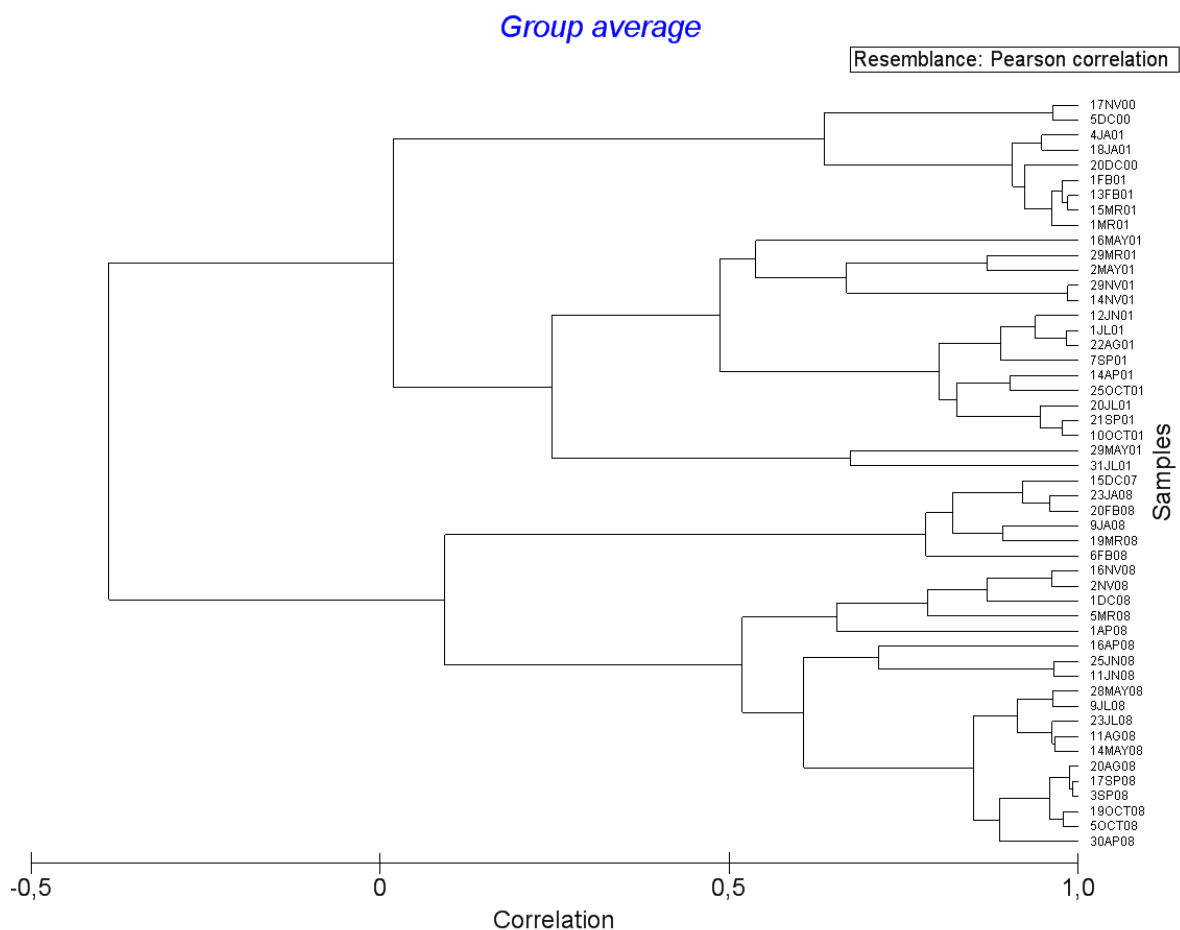


Figure 10. Cluster analysis of 2001 and 2008 samples according to environmental parameters.

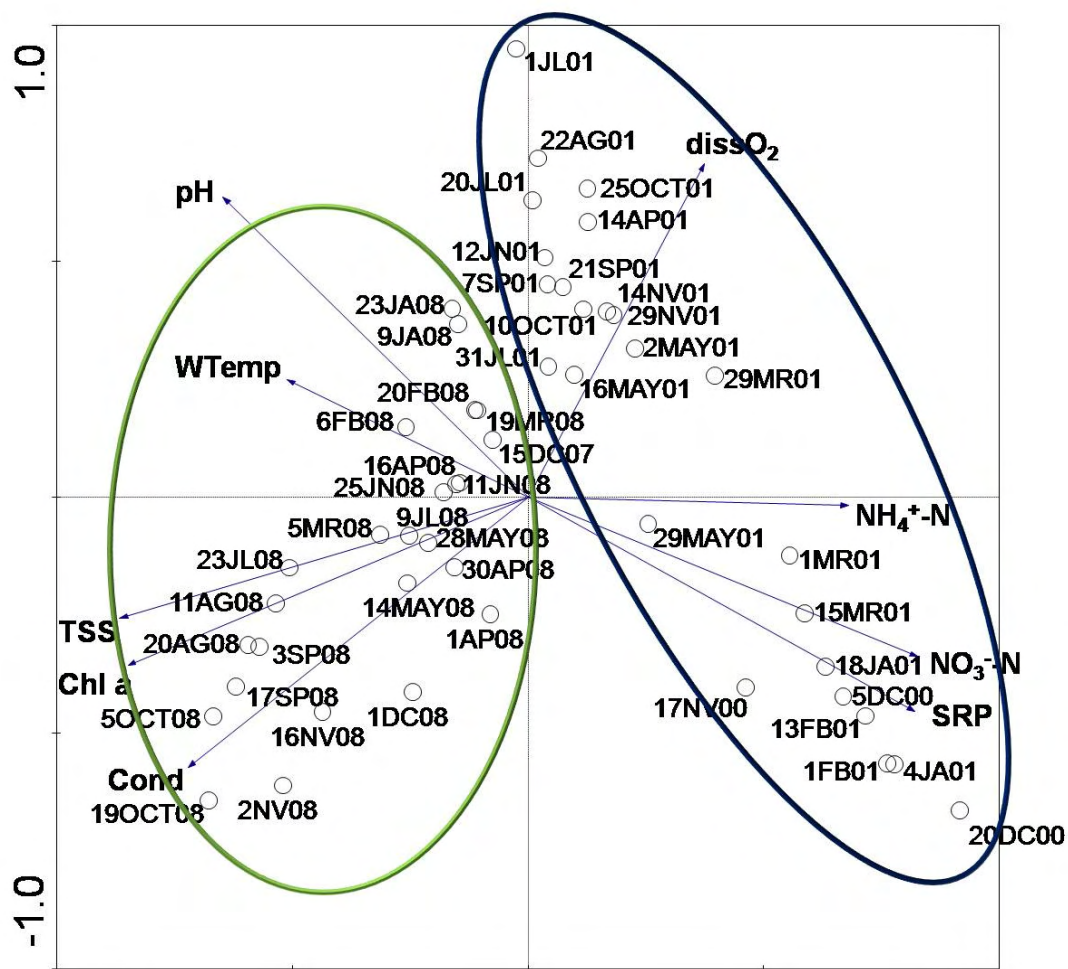


Figure 11. Principal Component Analysis relating fortnight samples from 2001 and 2008 and their distribution according to environmental parameters.

Table 5: Summary of ordination analysis of samples using environmental parameters of the present work and the results from 2001 obtained and described by de Figueiredo *et al.* (2006).

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.516	0.201	0.117	0.057
Cumulative percentage variance	51.6	71.7	83.4	89.1
Of species data				
Sum of all eigenvalues	1.000			

The dendrogram (Figure 10) and PCA (Figure 11) relating fortnight samples from 2001 and 2008 showed a clear segregation of samples from both years, independently from season, as illustrated by the axis 1 of the PCA. The negative side of the first axis was defined by 2008 samples while the positive side was

defined by 2001 samples. This axis was mainly related to TSS, Chl *a*, conductivity and pH (higher in all 2008 samples). The second axis showed to be mainly related to typical seasonality in 2001 but not in 2008 where samples are mixed. This axis was defined by sample 1JL01 in the positive side while autumn samples 19OCT08 and 2NV08 along with winter sample 20DC00 defined its negative side. This axis was mainly related with dissolved oxygen, pH and conductivity. These first two axes showed to explain 72% of the total variability among samples (Table 5).

4. Discussion

4.1. Environmental parameters

Vela Lake is considered a eutrophic lake with high P and N levels (Antunes *et al.*, 2003). The external nutrient loading comes from freshwater systems and source inflow from surrounding catchment area (Sigee 2005). Nitrogen is an essential compound of living organisms and has a wide range forms such as nitrates ($\text{NO}_3\text{-N}$) and ammonium ($\text{NH}_4\text{-N}$). Relatively to these forms, while recent studies (Antunes *et al.*, 2003; Abrantes *et al.*, 2006; de Figueiredo *et al.*, 2006) recorded high nutrients concentrations during winter period (December to April). In the present work the concentrations for nitrates were very low (≤ 0.1 mg/L) or undetectable throughout the all study period. Phosphorus is another essential element present in all living systems, as a structure molecule, storage component and energy transformation (Sigee 2005). In this work, phosphorus is presented as SRP, and was undetectable during all year, except in July. This low availability is also due to the low inflow levels into Vela Lake. These nutrients concentrations and variations are not concordant with those described for eutrophic lakes (Anderson *et al.*, 2002; Schindler *et al.*, 2008) or either by de Figueiredo *et al.* (2006) for Vela Lake. According to Abrantes *et al.* (2008) the hydric regime of the Vela Lake is influenced 10% by rainfall, and the other 90% by fluxes (surface and subterraneous) discharges into the lake. The study year (from December 2007 to December 2008) was warmer and drier, with lower rainfall than usual, which can explain the low nutrients concentrations recorded.

Silicon is a common element in the Earth, presented mainly as silica (SiO_2). This compound has little biological significance for freshwater microorganism except for diatoms, as it is its major cell-wall constituent (Sigee 2005; Domis and Mooij 2007). During the study period, silica availability was high, except from February to April when concentrations became lower than 0.3 mg/L which is a limitation for diatoms growth as previously reported (Barros *et al.*, 1993).

Temperature is one of the most important environmental parameter that determines the growth and survival of microorganisms (Sigee 2005; Paul 2008). Over the past century the global temperature has increased on average by 0.6°C (Domis and Mooij 2007; Paul 2008). ATemp and WTemp values for Vela Lake were high and very close and the oscillation of the first one affects, as expected,

the second. This happens because this lake has no thermal stratification, low profundity and it is exposed to the influence of the wind. As expected, the highest temperatures were registered in July (summer period) and the lowest in December (winter period). High temperature environments result of solar and geothermal heating or/and human activity; it is often related to higher values for pH, oxygen concentration and hydrostatic pressure (Sigee 2005).

The present work has registered higher temperatures, pH and conductivity levels by comparing to previous studies made on this lake (de Figueiredo *et al.*, 2006). The higher turbidity also observed as well as the higher pH values lead to dominance of Cyanobacteria in shallow eutrophic lakes (Reynolds *et al.*, 2000; Kemka *et al.*, 2006). The alkalinity of water results from photosynthetic and respiratory activities that cause a decrease in CO₂ values and consequent disruption in equilibrium and pH increase (Whitton and Potts 2000; López-Archilla *et al.*, 2004; Sigee 2005). Vela Lake has been already characterized as alkaline (Fernandes 1999; de Figueiredo *et al.*, 2006; Danielsen 2009), and this study can confirm that during the entire study period the pH values were higher than 8.

Conductivity is dependent on the ionic strength of the medium, so the conductivity will be greater the higher the concentration of ions. The highest values registered for conductivity (527 to 995 µS/cm) are due to the dry year with low rainfall. The lowest value was recorded during a rainfall period.

The dissolved oxygen is affected by organic matter degradation as well as photosynthetic and respiratory activities (Miranda *et al.*, 2001). The values recorded during winter period (December07 to February08) were high (never below 10 mg/L). In the summer period it was verified a decrease in dissolved oxygen values due to the registered temperature increase. The same variation was recorded regarding oxygen saturation (%O₂), due to the same situation. Unlike this work, the values obtained in 2001 and detailed in the work of de Figueiredo *et al.* (2006), were higher in summer period and lower in winter period.

Chl *a* is a distinguishing constituent of phytoplankton and it is widely used as a convenient index of phytoplankton bloom (Whitton and Potts 2000). In this work it was high during all year with the highest concentrations (> 200 µg/L) from

August to November. These values were way above the ones recorded in 2000/1 (de Figueiredo *et al.*, 2006) and consistent with bloom formation.

4.2. Phytoplankton dynamics

The studies made in Vela Lake (Antunes *et al.*, 2003; Abrantes *et al.*, 2006; de Figueiredo *et al.*, 2006; Lopes *et al.*, 2009) demonstrate seasonal phytoplankton dynamics where diatoms dominate during winter period under conditions of low temperatures and high nutrient levels. In early spring Chlorophytes dominate the phytoplankton and the cyanobacterial dominance is usually observed in summer until autumn period (highest temperatures and lowest nutrients availability). In the present work, the abundance of Chlorophytes and Diatoms was stable during all the study period but with higher concentrations at the same time and in accordance with the higher concentrations of cyanobacteria (August to November 2008). Relatively to Chlorophyta, it was the group with highest densities after cyanobacteria. In the work of de Figueiredo *et al.* (2006) this phytoplankton group was present in March and April with higher densities. Diatoms succession can be explained by silica availability. However, their densities were much lower by comparing to 2001 data (7.81×10^4 until 1.32×10^6) (de Figueiredo *et al.*, 2006). During the study period when diatoms densities increase (February and June) silica levels decrease. This is in accordance to the findings of Domis 2007 (Domis and Mooij 2007). In this work, the growth of the chorophycean *Botryococcus braunii* and of the diatoms of the genus *Aulacoseira* were related to high water temperatures as previously recorded by de Figueiredo *et al.* (2006) at Vela Lake. High values for TSS, conductivity and Chl *a* were also related to an increase in the development of *Tetraedron minimum* and *Tetraedron caudatum*, and *Pediastrum* spp. as well as the *Aulacoseira* spp.. The growth of *Tetraedron* spp. showed to be also promoted by an increase in pH values.

In shallow lakes with no thermal stratification just like in Vela Lake, phytoplankton productivity shows little variation during the year, the main external factor productivity is rain and wind, which, in turn, exert influence on the nutrients (Ganf 1974). More, climate change may also cause quantitative changes in

phytoplankton community dynamics, shown as changes in phytoplankton species composition or changes in seasonal succession of phytoplankton groups (Domis and Mooij 2007; Paul 2008; Hu *et al.*, 2009) by favouring cyanobacteria growth over diatoms and green algae's development. This study is concordant with that, as it was verified a low succession dynamics and diversity of phytoplankton with predominance of cyanobacteria (filamentous forms) during all the study period when higher temperatures and lower rainfall were registered. Some authors (Scheffer *et al.*, 1997; Dokulil and Teubner 2000) relate the dominance of filamentous cyanobacteria forms to shallow turbid lakes. Factors such as reduced transparency, decreased biodiversity, oxygen depletion, odour and taste compounds and toxins production are also associated to cyanobacterial dominance (Dokulil and Teubner 2000; Downing *et al.*, 2001). In the present study, Cyanobacteria abundance was higher during summer period, as recorded by other authors (Dokulil and Teubner 2000; Domis and Mooij 2007; Paul 2008), achieving the highest densities between August and November when the lowest oxygen levels and nutrient and silica concentrations were recorded along with the highest values of pH, conductivity, Chl *a* and TSS as well as high temperatures. The filamentous forms of Cyanobacteria were the most abundant (including the *taxa Aphanizomenon flos-aquae* and *Cylindrospermopsis raciborskii*), followed by the colonial forms like *Microcystis* spp.. However, Scheffer and collaborators (1997) describe that when winter period is not too cold the dominance of these forms can even persist throughout the year such as observed for Vela Lake in 2008 (unlike reported in 2001 when this dominance of cyanobacteria (mainly of *Aphanizomenon flos-aquae* and *Pseudanabaena* sp.) was verified only from May until November).

The cyanobacteria dominance observed during the study period can be also explained by a combination of several factors that led them to survive under extreme conditions. They have properties such as gas vesicles (for migration in water column), low CO₂/high pH optimum and excretion of toxic compounds that inhibit the growth of algae. The ability of cyanobacteria (such as *Microcystis* spp.) to migrate vertically in the water column gives them competitive advantage by storing internal phosphorus reserves, and therefore survive under limited

concentrations of this compound (Dokulil and Teubner 2000). Some species like *Aphanizomenon flos-aquae* and *Cylindrospermopsis raciborskii* are also able to fix nitrogen (Dokulil and Teubner 2000). This capability could be the explanation of the highest densities registered for these two species from June to December, were the nitrate values were undetectable. Danielsen 2009 made a compilation of the recorded alga flora in all studies made on Vela Lake and blooms of *Cylindrospermopsis raciborskii* have never been documented, although the occurrence of *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* blooms are already well documented for Vela Lake (Abrantes *et al.*, 2006; de Figueiredo *et al.*, 2004a; de Figueiredo *et al.*, 2004b; de Figueiredo *et al.*, 2004c; de Figueiredo *et al.*, 2006; de Figueiredo *et al.*, 2009). These species have the ability to produce seriously dangerous toxins. *Microcystis* spp. can produce microcystin that have been reported in Portuguese freshwater bodies as Vela Lake (Vasconcelos *et al.*, 1996; Vasconcelos 2001a; Vasconcelos 2001b; Vasconcelos and Perreira 2001, de Figueiredo *et al.*, 2004c). *Aphanizomenon flos-aquae* is able to produce Saxitoxins, or PSP, that are neurotoxins that retard the movement of sodium ions through nerve cell membranes, and may block the flow of nerve impulses to cause the symptoms of PSP toxicity, which include paralysis and disorientation. *Aphanizomenon flos-aquae* was reported in Vela Lake in May 2001 (de Figueiredo *et al.*, 2006) and related to low nitrogen levels. In the present work it was documented in April 2008 and from June to December 2008; its development was correlated with high values for water temperature, TSS and Chl *a*. The filamentous, nitrogen fixing, freshwater *Cylindrospermopsis raciborskii* was first recorded in Java, Indonesia and described as *Anabaenopsis raciborskii* (1912) and classified as a tropical species optimally growing at 25 °C. The genus *Cylindrospermopsis*, with *C. raciborskii* as type species, was only established in 1972 (Hawkins *et al.*, 1985; Druart and Briand 2002; Vidal and Kruk 2008; Kokocinski *et al.*, 2009). Since then, it has shown to be abundant in lakes and rivers in many tropical and subtropical areas, and is increasingly being recorded in temperate regions. It has been found in Australia, Europe, Japan, East and South-east Asia and USA (Falconer and Humpage 2006) but its occurrence has been also reported in cooler regions of the Northern Hemisphere (Neilan *et al.*, 2003;

Falconer and Humpage 2006; Vidal and Kruk 2008). This demonstrates a high adaptability and competitive advantage which enabled its rapid expansion in different parts of the globe (Falconer and Humpage 2006). Its high competitiveness in eutrophic environments together with the ability to form blooms and produce toxins make this cyanobacterium the most studied one both in the ecological and public health fields. It has the ability to produce various toxins, such as Cylindrospermopsin (CYN) and saxitoxins (Falconer and Humpage 2006; van Apeldoorn *et al.*, 2007; Fastner *et al.*, 2007; Rucker *et al.*, 2007; Kokocinski *et al.*, 2009; Messineo *et al.*, 2009). CYN is a tricyclic alkaloid that can also be produced by the species *Umezakia natans*, *Aphanizomenon ovalisporum*, *Aphanizomenon flos-aquae* and *Aphanizomenon gracile*, *Anabaena bergii* and *Anabaena lapponica*, *Raphidiopsis curvata*, *Lyngbya wollei* (Falconer and Humpage 2006; van Apeldoorn *et al.*, 2007; Fastner *et al.*, 2007; Rucker *et al.*, 2007; Kokocinski *et al.*, 2009; Messineo *et al.*, 2009). CYN and its toxicity to the human population (with inhibition of protein synthesis and causing pathological symptoms in liver, kidneys, spleen, thymus, heart and skin) were first reported in 1979 in Palm Island (Australia) (Kokocinski *et al.*, 2009; Messineo *et al.*, 2009). In the present work, the development of *C. raciborskii* was significantly correlated with higher levels for conductivity, TSS and Chl *a*. In Portugal, this species had already been reported in several central and south lakes and reservoirs, showing lethal toxicity in mousse assays (Saker *et al.* 2003; Codd *et al.* 2005; Valério *et al.* 2005). Interestingly, by comparing to data from 2001, our results showed a clear segregation of samples from 2008 suggesting particular environmental conditions at the lake may enhance *C. raciborskii* growth. These are mainly related to higher levels of TSS, Chl *a*, conductivity and pH; nutrient concentrations remained very low throughout the year. More, in 2008 there was not a typical seasonality in environmental parameters (as recorded in 2001- de Figueiredo *et al.* 2006) which may also explain the persistence of this species throughout the study period.

5. General Conclusions

The year of 2008 was characterized as a warm and dry year by comparing to the previous data which resulted in higher concentrations of total suspended solids and chlorophyll *a*. The nutrient levels were undetectable during most of the study period, probably due to the low precipitation levels. The present study allowed us to conclude that, under these conditions, the seasonal succession of phytoplankton community was less coherent with those described from previous works made on this and other eutrophic lakes. Nutrients unavailability can be responsible for the decrease of algal diversity, leaving cyanobacteria as the most competitive phytoplankton group and enhancing the formation of blooms. The high temperatures, generally above 14°C, also favoured cyanobacterial dominance (particularly by *Aphanizomenon flos-aquae*) but also showed to be related to an increase in densities of chlorophycean such as *Botryococcus* spp. and of the diatoms of the genus *Aulacoseira*. High values for TSS, conductivity and Chl *a* showed to enhance the development of the cyanobacteria (*Aphanizomenon flos-aquae* and *Cylindropselmopsis raciborskii*) but also *Aulacoseira* spp. and chlorophycean *Tetraedron* spp. and *Pediastrum* spp.. The growth of *Tetraedron* spp. showed to be also promoted by an increase in pH values.

It is known that cyanobacterial abundance can increase during warmer years suggesting that global warming may lead to long term effects on phytoplankton community. This study showed significant environmental differences among 2001 and 2008 samples and, in 2008, there were recorded increased values for Chl *a*, TSS, pH and conductivity which proved to be important factors behind the enhancement of the development of *C. raciborskii* blooms. Consequences of cyanobacterial blooms can be extremely severe, depending on the species involved. Further works should evaluate the presence of cyanotoxins at this lake and monitor them. It is also important to verify the responses of cyanobacteria to changing environmental patterns associated to global climate change.

6. References

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